VARIABLE FREQUENCY DRIVE APPLICATION FOR MITER GATE

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1. INTRODUCTION

In 1994-5, at Allegheny River L/D #4, the Pittsburgh District replaced the centralized miter gate hydraulic system with four new unitized miter gate actuators. The central system, installed in the 1920s, was a trouble shooting and maintenance headache because of its complexity with all the piping, valves and machinery (water turbine pumps, miter gate components, etc.). Many of the parts were corroded and brittle. When parts failed replacements were no longer available and repair costs were becoming prohibitive. Figure 1 shows some, of the many, components that made up the original system.

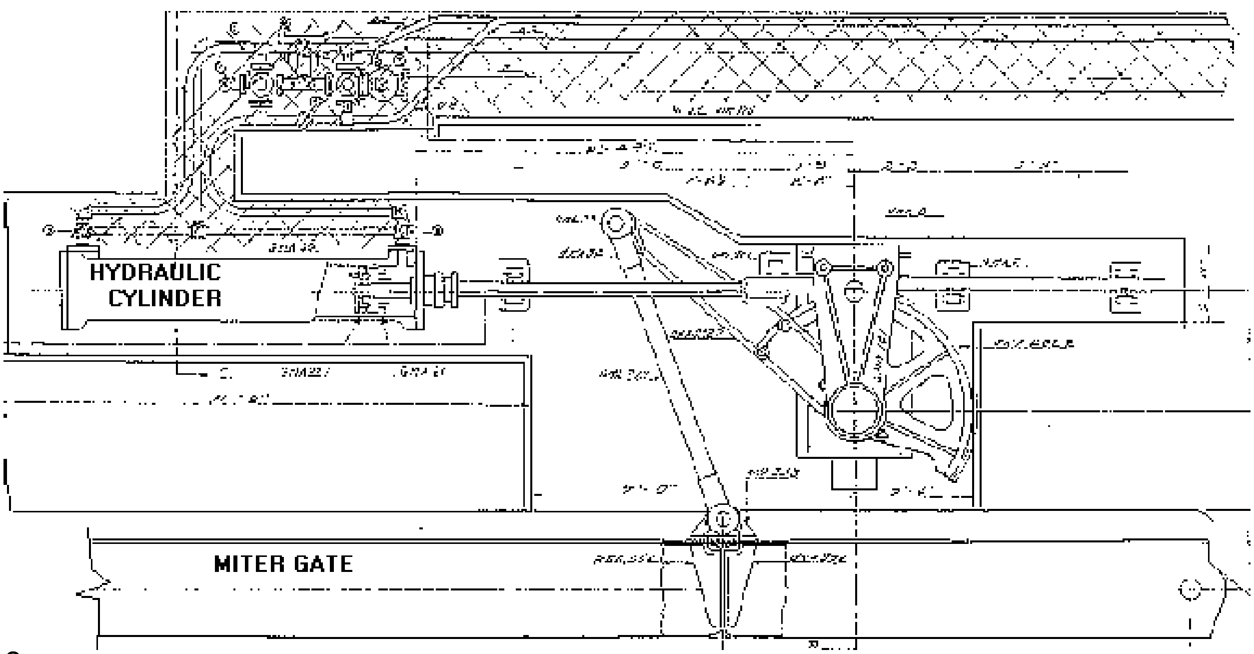

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FIG. 1 - ORIGINAL MITER GATE MACHINERY PLAN VIEW

For years, in other industries, whenever a machine's speed had to be varied the standard was to use a DC motor. Belts and pulleys were used with AC motors, but to obtain infinite variable speed the standard was the DC motor. Vary the voltage to a DC motor and its speed varies, do the same to an AC motor and the speed remains the same, and, if the voltage is too low the motor can burn up. DC motors have a high initial cost, are complex in construction and require more maintenance then AC motors, and, because of these reasons, are not an answer to replacing hydraulic systems.

The changes in AC motor control lead to improvements in the miter gate operating systems. At several Pittsburgh District locks, the central hydraulic system was replaced with a dedicated hydraulic system located next to each gate leaf. The dedicated system consists of pumps and reservoir, hydraulic cylinder, rack, sector gear and strut arm. Gate speed control was obtained through the use of valves located at each hydraulic cylinder. This works well but is not energy efficient, e.g. the hydraulic pump maintained pressure whether or not the gate was being operated. Also the many parts create additional maintenance.

The AC squirrel cage induction motor has low initial cost, is simple in construction and has high reliability. But, for years there was no easy way to provide variable speed. With the emergence of solid state devices, and, in particular the high speed switching transistor the variable frequency drive was developed. The VFD is inexpensive, dependable, and modular in design making for ease of maintenance. Its self-diagnosis facilities and modular design allows for speedier trouble shooting for quicker resolution of breakdowns.

Using this new technology, the dedicated hydraulic system was further simplified into two main components. The VFD (variable frequency drive controller) and the drive actuator unit (DAU). Figures 2, 3 and 4 show the DAU.

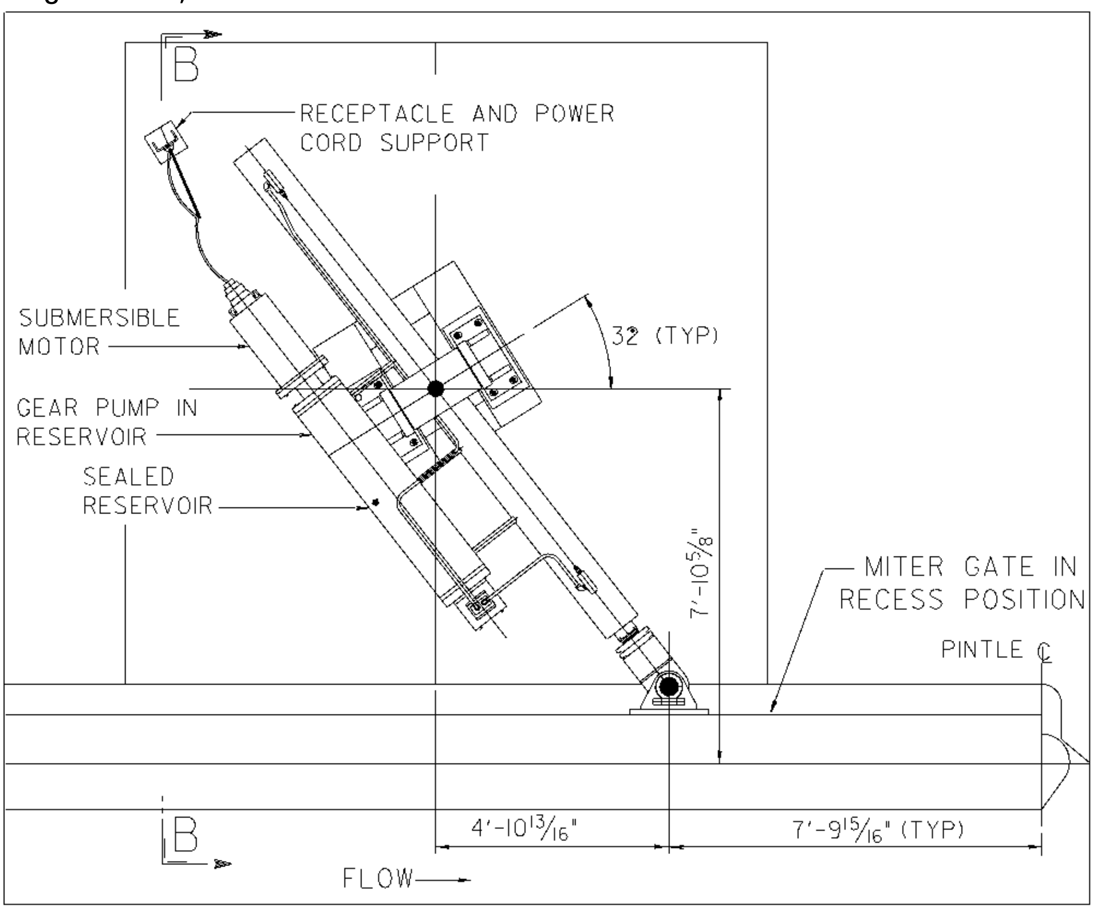

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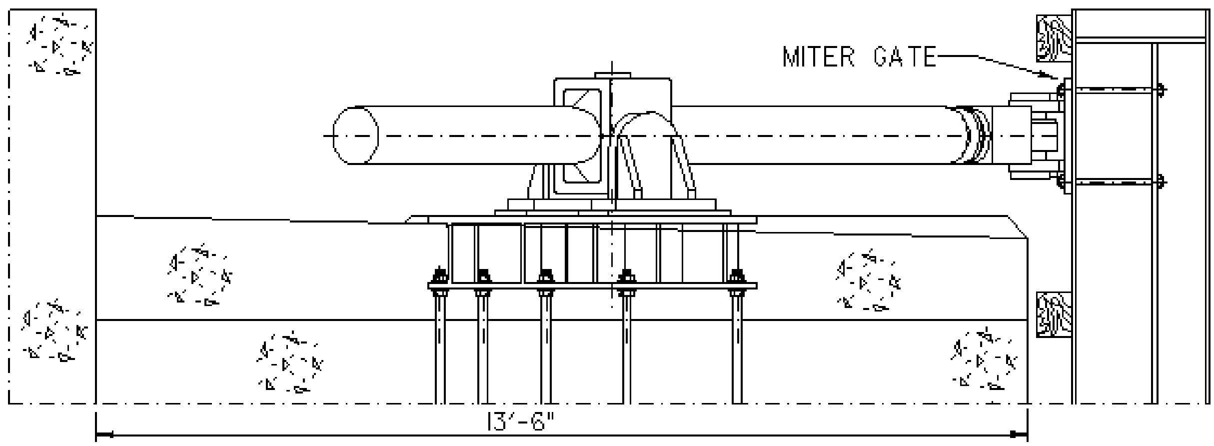
FIG. 2 - NEW MITER GATE MACHINERY PLAN VIEW



NOTE: HYDRAULIC POWER PACKAGE (RESERVOIR, MOTOR & PUMP) NOT SHOWN.

FIG. 3 - SECTION B-B

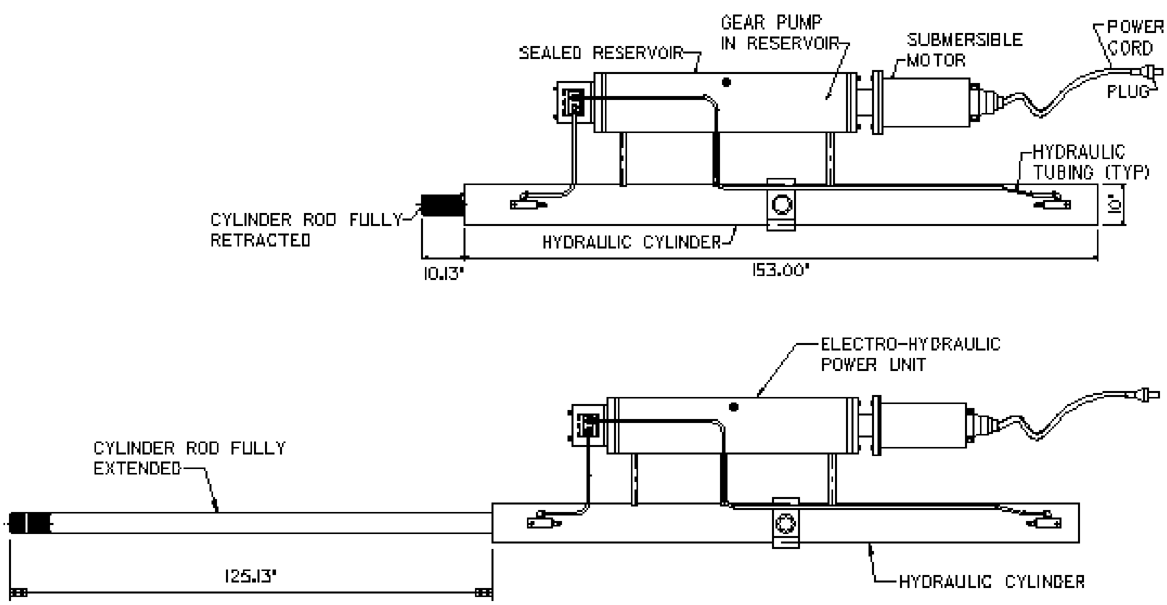


FIG. 4 - DAU PLAN VIEW

The DAU is a modular unit consisting of electric motor, pump, hydraulic cylinder, oil and control valves. The DAU is controlled by the VFD through a single 4/C cable.

The cost of a VFD/DAU system is less than a standard installation (i.e. hydraulic pumps, separate hydraulic cylinder, rack and pinion gears, etc.) and the initial installation is even cheaper if instead of the VFD control hydraulic regulating valves are used for control but in this case the electric bill will be higher since the motor runs even when the gate is stopped.

2. VARIABLE FREQUENCY DRIVE SYSTEM BASICS

a) The details of how a VFD works has been covered in a paper presented at the 1995 E/M conferences [1]. Basically a VFD controls a motor by changing the power supply frequency from 0-60 Hz. The speed of a A/C induction motor is directly proportional to the power supply frequency, e.g. a 4 pole motor=s speed when the frequency is 6 Hz is 180rpm* and at 60 Hz is 1,800rpm* (*actual speed is slightly less depending on the load).

b) The details of harmonics generated by VFDs has been covered in a paper presented at the 1995 E/M conferences [2]. Whether or not harmonics are a concern may require some research. According to a article from EPRI (Electric Power Research Institute)[3], A... transformers can generally be loaded with 30 to 40% of their load being composed of VFDs and still have a voltage distortion of less than 5%.@.
The final analysis for determining if harmonics are a problem is left up to the designer to investigate, e.g. VFDs can, in some instances, generate harmonic currents or cause transient surges, particularly where there are capacitors located elsewhere in the system [4].

c) The VFD allows a motor to start slowly without shock. This performance characteristic, some times called soft-start, initiates a gentle start so that there is a minimum wear on gears, drive shafts, coupling, etc.. The result is longer equipment life and greatly reduced maintenance costs [4].

3. OPERATION

The DAU unit is controlled by a panel mounted control lever (joy stick). The lever closes a switch and rotates a potentiometer. The potentiometer movement varies a low voltage signal to the VFD and this change in voltage determines direction and final speed of the gate. A preset ramp determines how long it takes to reach final speed. The controls are located in a shelter at each end of the lock chamber.

Sequence of Operation:

1) At the control shelter, the on/off switch is turned Aon@ (this switch protects against accidentally leaning on the control lever and operating the gate).

2) The lock operator then moves the lever fully in one direction (stick is moved in one direction for opening and opposite direction to close).

3) DAU accelerates up to speed following the preset 30 second ramp (adjustable at the VFD). Ramp time is thirty seconds from zero to full speed.

4) Full speed is maintained until nearing the final position, where the operator moves the stick away from full speed

to some slower speed and finally releasing the stick and the DAU proceeds to decelerate in accordance with the preset stopping ramp. During this time the gate can be feathered (walked) into position with slight movements of the stick, slow enough that you can hardly hear the gate shut.

5) The stopping ramp is preset at 3 seconds (adjustable at the VFD) to go from full speed to stop.

6) Both starting and stopping ramps are linear, e.g. if the gate is moving at half speed then the stopping ramp is 1.5 seconds.

7) At any time during operation the operator can vary the speed by moving the stick to an intermediate position and release the stick to go into the stopping ramp.

8) During normal operation total operating time is about 90 seconds, in both directions.

9) The energy bill is low since the only time power is being used is when the gate is moving.

10) Should a VFD fail the spare VFD unit can be replaced in about 15 minutes. The spare DAU requires longer to replaced since it weights about 7,500 lbs.

4. PROBLEMS AND SOLUTIONS

a. Problem: Initially the VFD and motor were not compatible i.e. the VFD was rated 20 HP maximum and the motor 30 HP.

Discussion: Design had determined that a 20HP motor was required. The VFD subcontractor supplied a properly sized unit, i.e. 20HP, but the motor manufacturer, to be conservative, advised the DAU subcontractor that the motor size had to be increased. The increase was from the 20HP to 30HP to insure that 1) the motor would not overheat since motors may experience excessive heating if operated continuously at slow speeds and 2) since it is a submersible motor was to be operated in open air its water cooling effect was lost. The motor manufacturer added an extra motor nameplate stating Asuitable for use on PWM 20 HP max., 30.5 amps max.@.
This mix up of motor and VFD sizes could have been avoided and the 20HP supplied, had the motor manufacturer known that the motor was not to be operated continuously at low speeds and the motor was only intermittent duty.
Even if the 20HP VFDs operated the 30HP motors satisfactorily, the VFDs still would of had to be replaced because the size 2 bypass starter violated NEC 430-83 Ratings, i.e. too small for a 30HP motor.

Solution: The VFD was replaced with a 30HP unit. In future work, include in the specifications that the DAU supplier provide the motor and VFD as a matched package from one manufacturer.

b. Problem: The system was started and immediately started having troubles -

1) At various times during the starting ramp a fault would occur called APeak Amps@ and shutdown the VFD.

2) During stopping a fault would occur called AHi Regen@ and shutdown the VFD.

Discussion:

1) APeak Amps@ occurs when excessive current was being drawn. This fault appeared to happen more often in cold weather, apparently due to additional load requirements, e.g. thicker oil. Also a 30HP motor requires more current then a 20HP, this extra current may have been enough to cause the unit to trip. The tripping occurred at various times during the starting ramp so other factors, such as weather, may have added the other little extra current that was needed for the fault to occur. Some current measurements were made and other then when the trips occurred the currents (load requirements) would easily be handled by a 20HP motor. It was never determined exactly what caused the high currents which initiated the faults.

2) AHi Regen@ occurs when the motor becomes a generator and puts power back into the VFD, (referred to as regenerated power). The miter leaf is an overhauling load, e.g. causes the motor to rotate in the same direction for a time after power is turned off, due to its high inertia. To absorb this energy some type of regenerative brake has to be included in the VFD.

Solution:

1) Actual solution - the 20HP VFD was replaced with a 30HP VFD. Theoretical solution - use a 20HP motor (because the calculated load was 20HP and motors operate at peak efficiency at, or near, their rated horsepower) but with the next size VFD, i.e. 30HP, because of the high inertia load.

2) A dynamic braking resistor package was installed on each VFD.

3) There has been no further problems since the dynamic braking package, surge suppression and the 30HP VFD have been installed. All four VFD systems have been trouble free.

5. DESIGN TIPS

a. Motor -

1) Use NEMA AB@ motor designed for use with VFDs. These have high dv/dt withstand capabilities, i.e. wound with thicker insulation [5]. The high dv/dt is due to the extremely fast switching of the VFD=s transistors and excessive lead lengths between the motor and the VFD. This has the potential to reduce the life of improperly applied motors, e.g. motor can suddenly fail by shorting out (fault between windings). Preventive measures are: use inverter duty motor, limit motor feeder length to less than 150 ft., install reactor on VFD output to reduce rise times (load torque requirements may be a consideration here)[6][7].

2) Use class AF@ motor insulation, i.e. high temperature. Motor will heat up if run for long periods at slow speed, but during normal operation the motor should be run so that class B insulation requirements are not exceeded [3].

3) Motor bearing failure due to common-mode voltage. Most power electronic converters have an output which is differential-mode which doesn't cause current to flow through the motor bearings and cause damage, e.g. pitting, fluting of the bearing surfaces[8].

b. Insure proper ventilation of the VFD. Overheating can shorten the life expectancy of electrical components or can lead to catastrophic failure [9]. Reference [9] contains recommendations for the installation of electrical and electronic devices to prevent the accumulation of heat and the resultant damage.

c. Maintaining miter gate operation is critical, therefore the VFD should have a bypass contactor. The bypass contactor is wired in parallel with the VFD and allows the gate to be operated in the event the VFD fails.

d. Cold weather operation: Although heat tracing was not applied to these DAUs, it may be required in extremely cold climates.

e. TM 5-811-13 contains information on motors and VFDs.

f. Surge protection should be installed on the VFD feeder.

g. Some manufacturers make both the motor and drive units.

6. CONCLUSION

The VFD system provides smoother control, uses less energy, is cheaper to operate, has a capital cost which is less then other systems, has less piping and therefore reduces the chance of oil leaking into the environment, is SCADA (supervisory control and data acquisition) compatible. Therefore, any replacement or new miter gate machinery projects should investigate using this type system.

7. REFERENCES

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